ELECTRIC -In-Air-X-Ray- DETECTORS FOR HIGH RESOLUTION VERTICAL BEAM POSITION MEASUREMENT AT THE ESRF

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Abstract

A simple and in-expensive electric device can detect the tiny fraction of the very hard X-rays that fully penetrate the dipole absorber structure and enter the free air space behind it. This in addition to an already installed, commissioned, and fully independent, system of 6 imaging detectors to measure the emittance [1-3]. It consists of a high-Z metal blade in conjuction with a small In-Air ionization slot that generates a direct strong electric signal allowing for nanometer resolution measurements of vertical beam motion in a spectrum upto 1KHz. The high resolution performance of this detector type is explained by the fact that it touches the heart and centre of the beam whereas other devices have to work on the edges or tails of the beam (X-BPMs) or feel the beam indirectly by wall-current pick-ups (electron-BPMs). The results obtained with prototypes are presented together with the prospects of an installation of 8 units in 2007. The intrinsic advantages of this In-Air detector like costs and simplicity, thanks to a total absence of cooling and UHV requirements, will be emphasized.

X-RAYS TRAVERSING THE ABSORBER

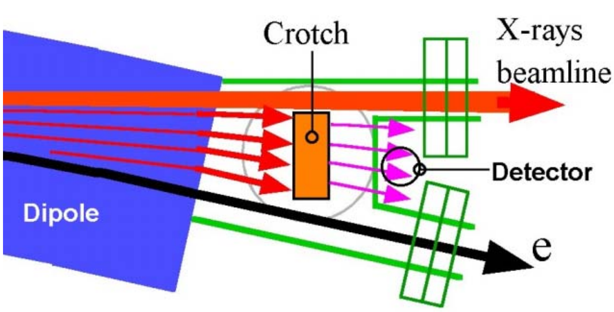

Figure 1: Top-view of detector's position just behind crotch.

A large part of the synchrotron light generated by the Dipole (B=0.86T, E=6GeV) is dissipated directly by an associated crotch absorber (fig.1). However, ~4ppm of this power is not absorbed and traverses the complete structure (of ~35mm Copper and 5mm Steel) to enter the free air behind.

This leakage power (~600uW/mRad hor. angle) is carried by the high energetic photons with a peak at ~170KeV energy and with a total flux of ~2E10 photons in the 100-300KeV range for a 1mrad hor.angle, at 200mA nominal Storage Ring current. These hard X-rays are detected directly by the use of a high-Z blade in combination with a small In-Air ionization volume.

A schematic side-view (fig.2) shows the detector, consisting of 2 parallel plates (or blades) separated by a small distance (typ. 1mm) in air, with the X-ray beam.

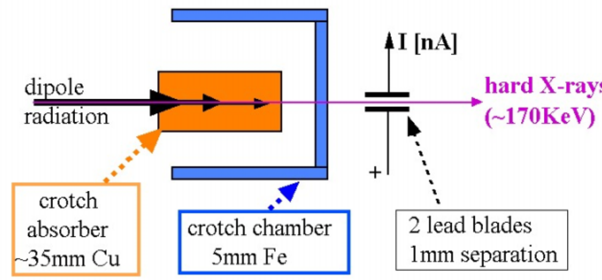

Figure 2: Side-view of the 2-blade electric detector.

One of the blades is connected to a DC bias voltage (typ. 50V), while the other blade is connected via a short coaxial cable to a high impedance electric measurement device (typ. 1Mohm input oscilloscope). The dimensions of the blades are 23x23mm. They are mechanically fixed to an electric isolator that itself is mounted to a miniature mechanical assembly allowing for the angle orientation in 2 planes and a vertical translation. This assembly is a commercial product with 3 DC motors for remote control of these 2 angles and the vertical position of the detector.

It is to be noted that the physical space available between the crotch chamber and the vacuum flanges is very limited and the detector design needs to be very compact and miniaturized so to fit in.

AIR IONIZATION BY X-RAYS HITTING HIGH-Z AT GRAZING INCIDENCE

The correct 2-plane-orientation and vertical position of the blade surface, made of a High-Z metal, with respect to the X-ray beam is crucial. The first alignment aim is to have the beam intercepted by the full area of the blade surface. It is to be noted that the X-ray beam dimensions at this point are horizontally large, i.e. exceeding the 23mm detector width, while vertically very small ~100um.

The sketch in the top part of figure 3 shows the upper blade surface at a small grazing angle (α) with respect to the X-ray beam. With the beam at the vert. position P a maximum of signal is generated. The graph in the lower part of figure 3 shows the signal output when scanning the detector vertically : Another signal is generated with the beam at position Q but of lower amplitude since the beam-surface angle is not optimum in this case.

The interaction of the high energy X-rays with the high-Z material causes, at the surface, a shower generation of secondary particles that themselves cause an ionization of the air molecules in the small volume between the 2 blades. This conductive state together with the applied DC bias voltage now allows for measurement of a small voltage by the 1Mohm instrument. The physics of the X-rays with the high-Z material, the subsequent particle generation, their exact nature, and their consequence of electric ionization in air are matters outside the scope of this paper and not further described here.

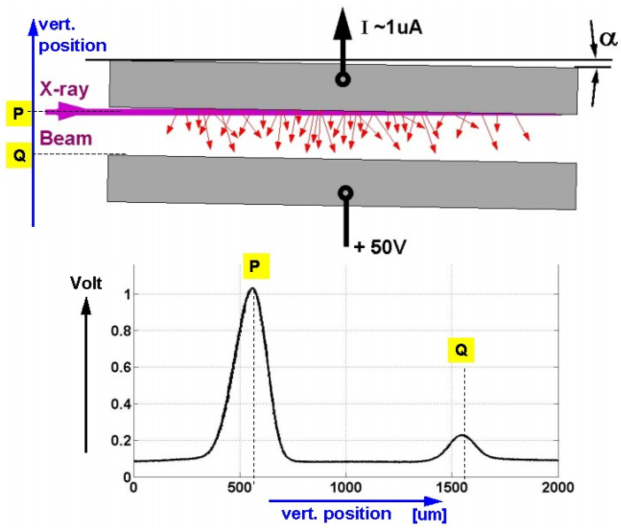

Figure 3: Top : sketch of the blade-surface at grazing incidence with the beam, Bottom: signal output when scanning the detector vertically through the beam.

The blades of a first prototype were both made out of Lead. Later Tungsten and Gold (coating) have been used with the advantage of better surface flatness quality. In a now more finalised version a single ‘interceptive’ blade made of Nickel with Gold coating is applied, while the 2nd blade (with the bias voltage) is made out of Aluminium.

The signal yield is of roughly equal strength for each of these 3 materials tested : ~1uA for our 23x23mm detector at 200mA beam current. With a distance to the source-point of ~1.8m the hor. acceptance angle is ~13mrad. The X-ray beam power intercepted here is ~8mW, or ~3E11 photons/sec. The 1uA currents amounts to ~6E12 electrons/sec so the actual ‘conversion gain’ is roughly a factor 20.

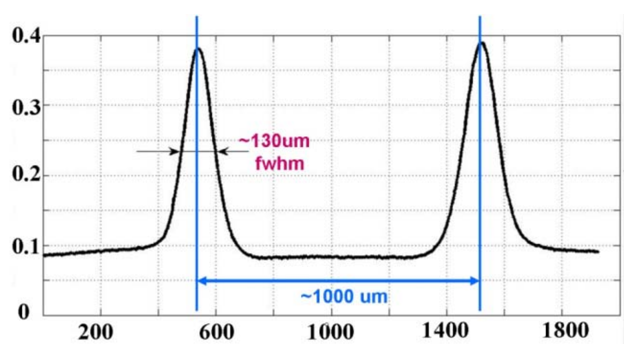

Figure 4: The signal output when scanning the detector position vertically with the blades parallel to the beam.

After installation the initial alignment & angle orientation of the detector is a re-iterative process that consists of scanning the detector vertically through the beam and (time-)recording the signal output, and repeating this at (slightly) varying transverse and longitudinal angles. The signal output in figure 4 shows the case where the blades are parallel to the X-ray beam : the two responses, separated by ~1mm, coming obviously from each of the 2 blades, with the signal strength roughly equal and of minimum width. The optimization of the 2 plane orientation of the blade is done by repeating this scanning/recording so to obtain the best grazing incidence and thus the maximum signal output of one of the blades (the ‘interceptive’ blade). After that the detector’s vertical position is slightly tuned so to be at ~1/2 of this maximum signal, i.e. on the steep slope of the signal. In this way the detector has now become a vertical position monitor with a sensitivity of ~10mV/um without any amplification of the crude detector signal.

RESULTS OF DC AND AC VERTICAL BEAM POSITION MONITORING

The detector positioned on the slope of a ~100um gaussian profile implies a limited range & linearity for use as a beam position monitor. This dislinearity is acceptably small (<10%) for beam displacements of +/- 20um. At the ESRF the schemes of slow & fast Closed Orbit correction & feedback results in an overall beam stability well within that range. The figure 5 shows the DC output (after filtering and amplification by a gain of 50) with the SR beam making a few local displacements of 10um value. The real resolution of the device for DC motion (estimated at <50nm with 1sec measurement time) can simply not be verified with the beam itself that has a residual & uncompressible DC motion above this value.

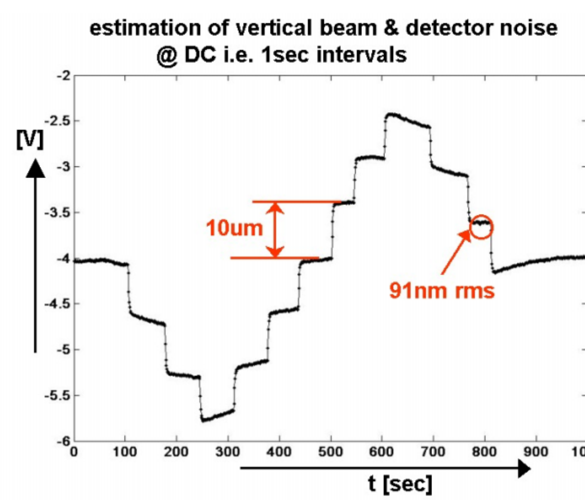

Figure 5: the DC output with the SR beam making a few local vertical displacements of 10um.

The performance in the AC range is shown in time recordings (fig.6) with the Fast Global Feedback going from a switched-off state to the active state [4]. The figure 7 shows the frequency spectrum of the detector with the Global Feedback active, the data was obtained over a 100sec period at 1Khz sampling frequency. Frequency components down to a few nanometer rms amplitude can be resolved.

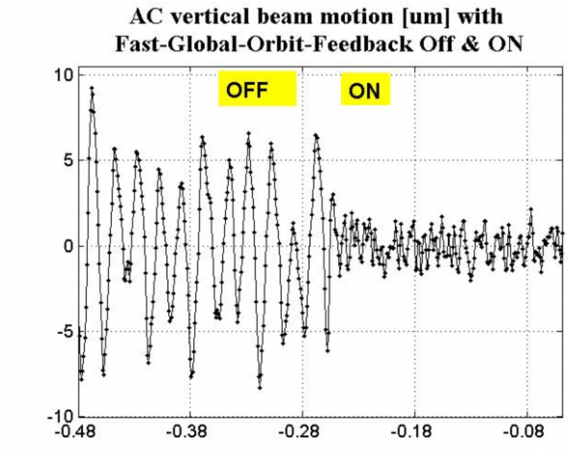

Figure 6: AC time recording of the detector output [um] while switching the ESRF's Fast Orbit Feedback Off-On.

Extensive tests have been carried-out to assess this resolution and to compare that with other diagnostics. The same data-acquisition modules with identical sampling periods & frequency was applied in these cases. Also in certain comparative tests the SR beam was made to oscillate at a known frequency & amplitude with the respective diagnostics scrutinized for their detection resolution. The In-Air blade-monitor, with its source-point in the middle of the dipole, benefits of a high vertical Beta of the ESRF machine lattice at that point (35 or 47m depending on even or odd cell number). It demonstrates a superior resolution to both the fast-electron-BPMs (installed in strait sections, i.e. low vert. Beta) and the classical X-BPM (photo-electric blades in UHV) that suffer from various limitations.

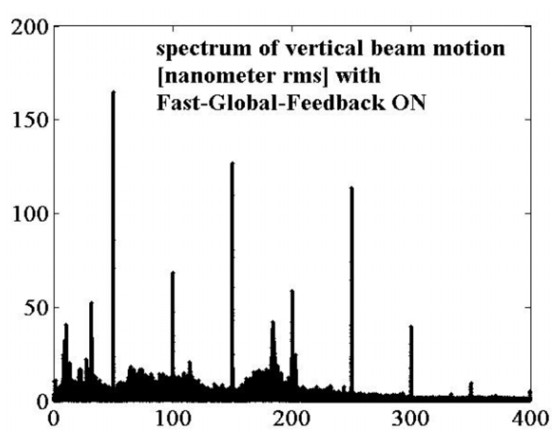

Figure 7: spectrum of vertical beam motion.

The rigidity of the fixation of the detector assembly to the vacuum chamber is crucial to avoid mechanical vibrations in the nanometer region that the detector is potentially capable of resolving. Tests performed with 10min. measurement times show a total absence of unknown lines in the freq. spectrum of the recorded signal.

CONCLUSION AND FUTURE PROSPECTS

It is shown that the small leakage power, carried by the high energetic part of the synchrotron radiation, that traverses absorbers and vacuum chambers and becomes accessible in free air, can be detected efficiently to constitute a very powerful diagnostic of high simplicity.

Although the nature of the dipole radiation imposes that the measurement of electron beam parameters is limited to the vertical plane only, the performance in terms of precision and resolution raises an exciting challenge for this field of detectors. This performance potential combines with the huge advantages of installing, aligning, operating and maintaining these devices in (accessible) free air and at negligible heatload, thereby liberating the designer of major concerns of UHV compatibility and cooling requirements so typical of other diagnostics systems.

The numerous tests performed on the 'blade-monitor', in comparison to other diagnostics for vertical beam motion measurement, have shown that it is of superior performance in terms of resolution. This detector clearly benefits from the fact that it can touch the heart & centre of the beam signal.

The prototype development of the electric blade-monitor itself was finalised in 2006. Appropriate data acquisition modules and associated software and device servers are now under procurement and development so that eight of these devices will be installed and commissioned in 2007 and made available to the accelerator operation for improved survey of vertical beam stability.

The performance and reliability of these detectors will be further evaluated then for deciding on the possibility of integrating them in the Fast Global Orbit Feedback system.

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